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(19) (CA) **APPLICATION FOR CANADIAN PATENT** (12)

(54) Process and Connection for Electrically Connecting Two Superconducting Cables

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(57) 15 Claims

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(54) Title: PROCESS AND CONNECTION FOR ELECTRICALLY CONNECTING TWO SUPERCONDUCTING CABLES

(54) Bezeichnung: VERFAHREN UND VERBINDUNG ZUM ELEKTRISCHEN VERBINDEN ZWEIER SUPRALEITENDER KABEL

(57) Abstract

A process for electrically connecting two superconducting cables (12) is characterized in that the cable sheath and/or the high-resistance coating of the superconducting wires are removed, when present, in order to expose the cable strands, the cable strands are beveled at their ends and the beveled surfaces (24) thus obtained at the cable ends (11) are laid on each other and mechanically compressed. A cable connection is also disclosed for electrically connecting two superconducting cables (12) which may be used for producing flat coils or layered windings in which the cable ends (11) freed from the cable envelope are surrounded by a sleeve (15) made of electroconductive material. The cable connection has a connecting casing (13) made of at least two parts which consists of two halves (13, 14) which surround the cable ends (11) and the sleeve (15).

(57) Zusammenfassung

Die Erfindung betrifft ein Verfahren zum elektrischen Verbinden zweier supraleitender Kabel (12), das sich dadurch auszeichnet, dass, wenn eine Kabeihülle und/oder eine hochohmige Beschichtung der supraleitenden Drahte vorhanden ist, diese entfernt wird, um die Kabelstrange freizulegen, die Kabelstrange an den Enden schrag zugeschnitten werden, und die gebildeten Schragflachen (24) an den Kabelenden (11) aufeinandergelegt und mechanisch mit Druck Beaufschlagt werden. Eine Kabelverbindung zur elektrischen Verbindung zweier supraleitender Kabel (12), die zur Herstellung von Flachspulen oder Lagenwicklungen verwendet werden kann, bei der die vom Kabelmantel befreiten Kabelenden (11) von einer Hülse (15) aus elektrisch leitendem Material umgeben sind, hat ein wenigstens zweiteiliges Verbindungsgehause (13), bestehend aus zwei, die Kabelenden (11) und die Hülse (15) umgebenden Gehausehalften (13, 14).

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Description

PROCESS AND APPARATUS FOR ELECTRICALLY CONNECTING TWO SUPERCONDUCTING CABLES

The invention concerns a process for electrically connecting two superconducting cables, as well as a corresponding cable connection.

Large superconducting cables that carry some 1000 amperes are usually produced in standard lengths of some 100 m. In order to wind very large superconducting coils for fusion magnets or energy storage devices, for example, several kilometers of such cable is required. For better success, the electrical connections between the different standard lengths are placed at the edges of the layers, in the case of layered windings, or on the outer radius of flat coils. To keep the local temperature increase with the design specifications of a coil, the energy consumed at the cable ends under operating conditions must be as low as possible. This can be achieved with windings that work only in DC mode by embedding the joints between the superconducting cables in highly electroconductive metals with a wide cross-section. For windings that work in alternating modes, the requirement of low eddy current losses leads to additional design constraints.

Two connections according to the state of the art are shown in Figures 1 and 2, which show cross-sections through two known cable connections for superconducting cable.

A cable connection with low electrical resistance may be achieved by overlapping and welding two cable ends. The overlap area is longer than current-carrying junction length necessary to transport the current. Before being overlapped and soldered, the cable ends are untwisted and embedded in a metal block made of highly electroconductive material. For superconductors based on intermetallic NB3SN strands, the soldering process must be carried out after the customary reaction heat treatment.

The longer the length of the overlap, the lower the transition resistance. However, the improvement of resistance for overlap lengths longer than one meter is practically negligible. If

an alternating magnetic field, for instance the field of a coil working in pulsed mode, is place transversely to the overlap connection, very large eddy currents are induced in the loop that consists of the two parallel cable ends, as shown in Figure 1 by a loop.

It is indeed possible to optimize the overlap length in terms of resistance requirements and eddy current losses, but this compromise is not acceptable for difficult operating conditions. The low transverse resistance, achieved by filling with soldering material and/or additional stabilization of the material, together with an overlap length that exceeds the lay of the cable twist, leads to eddy current losses that are higher by one to two degrees of magnitude than the superconducting cable. Under this condition, a large field pulse (B, B) can lead to unacceptably large energy losses at the transition area.

Another problem of such cable connections is the low degree of mechanical strength. Tensile stress in the cable can lead to sheering strain on the cable connection. To avoid such a sheering strain, additional reinforcement must be provided.

Figure 2 shows an alternative cable connection, which is an obtuse connection in which the contact surface runs perpendicular to the cable axis. The obtuse ends of the cable can be connected by welding or soldering. The main advantage of this type of cable connection lies in the fact that no additional eddy current losses occur. The AC losses are comparable to those of a blank conductor, since the transverse resistance is reduced over a section that is much shorter than the lay of the cable twist.

Lower transition resistance in such a cable connection can only be achieved by surrounding the welded ends with a thick copper sleeve. The main disadvantage of this technique lies in the fact that a large amount of space must be kept free at the cable ends so that welding tools and X-ray devices to monitor the welding can be brought to bear. However, in most coils for fusion devices, this space is not available. Another requirement of connections for large NB3SN magnets is compatibility with the winding reaction technique. This means that the connection must be produced before the reaction heat treatment, i.e., without significant thermal stress on

the superconductors. The treatment and handling of the connection after the reaction process must be limited to measures that do not require the superconductors to be moved.

The goal of the invention is therefore to develop a process for electrically connecting two superconducting cables and to create a corresponding cable connection that meets the requirements in terms of low electrical resistance, low eddy current losses, a compact overall size, high mechanical strength and low production risk.

In the following, the invention is described by way of examples with the aid of Figures 3 through 9:

Figure 3 shows a longitudinal section of a cable connection in its simplest form of development;

The steps for producing a cable connection using a connecting casing are shown in Figures 4a through 4d, in perspective, and in Figures 5a through 5d, in aspect view.

The different production steps are shown in cross-sectional view in Figures 6a through 6c;

Figure 7 shows a longitudinal section of a cable connection according to the invention in a different development form;

Figure 8 shows a cross-section of the cable connection in Figure 7; and,

Figure 9 shows a perspective, exploded view of a connecting casing for the cable connection according to the invention.

If the superconducting cables are not monolithic, the cable ends are mechanically compressed, after removing the copper sleeve and any other components, in a copper sleeve, leading to a reduction in the cross-section, for which reason no additional eddy current losses occur, because no loops are formed.

The cable ends are then cut at the smallest angle compatible with the necessary strength requirements, typically at an angle of 15 to 20° with respect to the longitudinal cable axis. Both parts of a copper sleeve are then laid on the cable ends with the beveled surface thus obtained; the parts of this copper sleeve do not have to fully surround the cable ends in the peripheral direction. In addition to the current path along the beveled surface depicted by lines in the figure, the cable connection produced in this way also has another current path running across the copper sleeve, thus reducing the overall resistance.

In producing such a connection, it is useful to provide a connecting casing that can consist of at least two casing halves.

Figures 4 and 5 show a schematic rendering of the production of a cable connection between two flat coils lying atop each other, in which the connecting casing is used in the manner shown in Figure 6. As shown in Figure 6a, one of the two casing halves can first be used only for the purpose of mechanically connecting the cable ends. This casing half is then removed after the heat treatment (Figure 6b) and a sealing casing half is applied, as shown in Figure 6c. Before this last step, a strip made of superconducting material may be inserted in the copper sleeve surrounding the cable ends, thus reducing the transition resistance through the beveled surfaces even more. It is useful to give the casing halves 13 and 14 a wedge shape in order to increase the tensile strength of the connection. For the same purpose, the sleeve 15 can also be wedge-shaped at both ends. Figure 9 provides an exploded view of the production of a cable connection using a connecting casing. To connect two superconducting cables, the cable sleeve 12 and any high-resistance coatings on the individual cable strands are first removed from the cable ends 11. Then, the cable ends are compressed and beveled at an angle of, for instance, 15 to 20° with respect to the longitudinal cable axis, producing the beveled surfaces 24.

The cable ends 11 are then placed in a copper sleeve 15, which consists of two halves, 15a and 15b. The connecting casing 13, made of steel and having two halves, 13 and 14, is then laid onto the copper sleeve 15. The casing half 14, in turn, consists of two halves, namely a compression plate 14a and a sealing plate 14b. The cable ends 11 are then compression-sealed by bracing the compression plate 14a with the casing half 13. This is achieved by screwing the

screws 18 through the openings 17 in the compression plate 14a into the threaded drill-holes 19 in casing half 13.

Since the superconducting cables are usually saturated with a coolant during operation, the casing half 13 and the compression plate 14a have cooling grooves 16, and the compression plate 14a also has an outlet 20 which corresponds to an outlet 21 of the sealing plate 14b.

The sleeve half 15b lying under the compression plate 14a has openings 22 and a longitudinal depression 23. The openings 22 are for introducing soldering material, if necessary, by which any space still existing in the cable ends may be filled. A strip made of superconducting material may be inserted in the longitudinal depression 23, in order to improve the electrical resistance properties.

Before the usual heat treatment applied to the cable, the casing halves 13 and 14, if necessary without the sealing plate 14b, are first of all fastened to the cable envelope 12, with sufficient mechanical stability, by spot-welding. After the heat treatment, the compression plate 14a can be removed in order to fill soldering material into the openings 22 and/or to insert a superconducting strip into the longitudinal depression 23. Finally, the casing halves are sealed with the cable envelope of both cable ends.

New Claims

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS.

1. Cable connection for electrically connecting two superconducting cables used for producing flat coils or layered windings, in which the beveled ends of both cables exposed at the connection point are laid on top of each other and surrounded by a sleeve made of electroconductive material, characterized in that the sleeve (15) consists of two parts and a connecting casing made of two casing halves braced together is placed as a stabilizer on the two sleeve halves (15a, 15b).

2. Cable connection according to claim 1, characterized in that the one casing half (14) consists of two parts (14a, 14b), one of which (14a) is formed as a compression plate and the other (14b) as a sealing plate.

3. Cable connection according to claim 2, characterized in that the compression plate (14a) has openings (17) for screws (18) and the other casing half (13) has the corresponding threaded drill-holes (19).

4. Cable connection according to one of the claims 1 through 3, characterized in that both casing halves (13, 14) have cooling grooves (16) running in the longitudinal direction.

5. Cable connection according to claim 2 or 3 and 4, characterized in that the cooling grooves (16) are formed in the compression plate (14a).

6. Cable connection according to one of the claims 2 through 5, characterized in that the compression plate (14a) has a coolant outlet (20) which works together with an outlet (21) in the sealing plate (14b).

7. Cable connection according to one of the claims 1 through 6, characterized in that the sleeve (15) surrounds the cable ends (11) only partially.

8. Cable connection according to one of the claims 1 through 7, characterized in that the sleeve (15) is made of copper.

9. Cable connection according to one of the claims 1 through 8, characterized in that the casing (13, 14) is made of steel.

10. Cable connection according to one of the claims 1 through 9, characterized in that the sleeve (15) has a longitudinal depression (23) for the insertion of a superconducting strip.

11. Cable connection according to one of the claims 1 through 10, characterized in that the sleeve (15) has openings (22) for filling soldering material.

12. Cable connection according to claims 10 and 11, characterized in that the longitudinal depression (23) and the openings (22) are formed in the sleeve half (15b) that lies below the compression plate (14a).

13. Cable connection according to one of the claims 1 through 12, characterized in that the casing halves (13, 14) are inwardly wedge-shaped at their ends.

14. Cable connection according to one of the claims 1 through 13, characterized in that the sleeve (15) is inwardly wedge-shaped at its ends.

15. Cable connection according to one of the claims 1 through 14, characterized in that the cable ends (11) are cut at an angle of about 15 to 20° to the longitudinal cable axis.

Fig.1

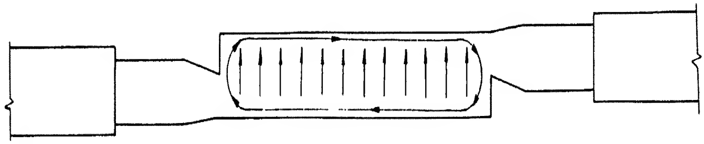

Fig.2

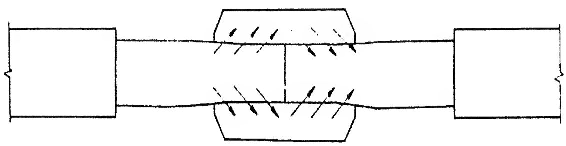

Fig.3

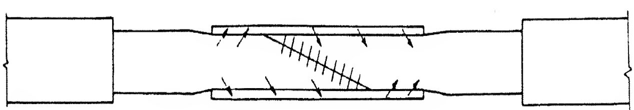

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Fig. 4

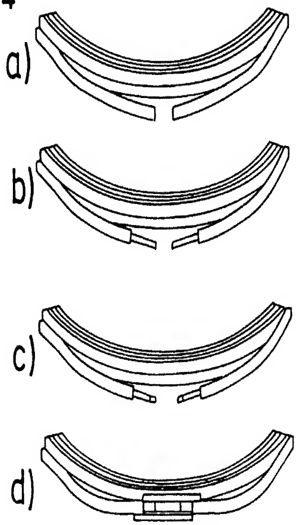

Fig.5

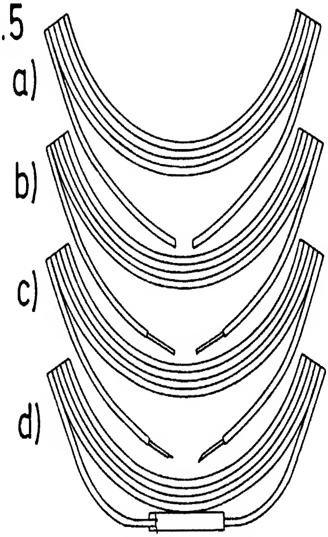

Fig. 6

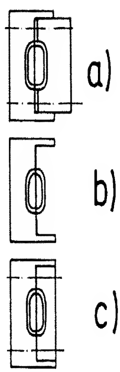

Fig.7

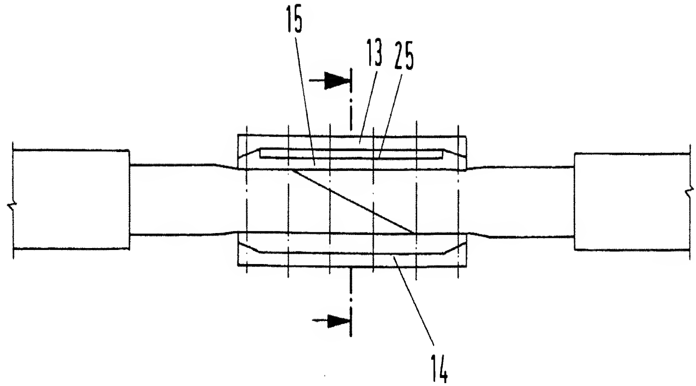

Fig. 8

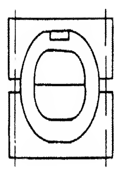

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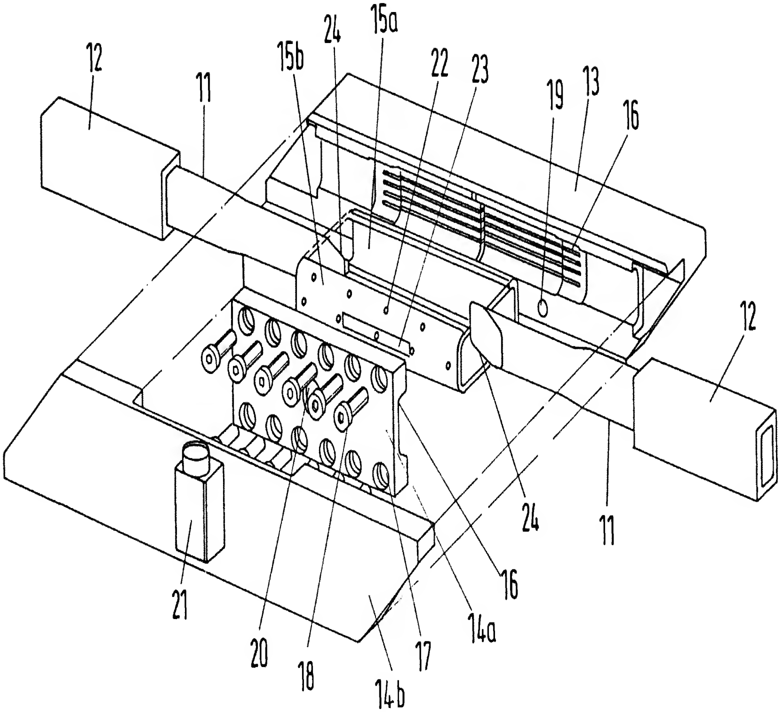
Fig.9



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